LBNL 4-Side Buttable CCD Package Development

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ABSTRACT

We have developed a precision, 4-side buttable CCD package for 2k×2k and 2k×4k format devices with minimal mechanical stress on the CCD, excellent thermal properties, reliable electrical connectivity, and shim-free mounting. We report on the package design, assembly and quality assurance procedures, measurements of flatness excursions when cooled from room temperature to 140 K, package performance and plans for future development.

Keywords: CCD, astronomical imaging, focal plane detectors, SNAP, Lawrence Berkeley National Laboratory

1. Introduction

This paper describes the development of a 4-side buttable CCD package for large format CCDs designed at Lawrence Berkeley National Laboratory[1]; these devices are thick (200-300 μm), fully-depleted, back-illuminated devices fabricated on high-resistivity silicon[2,3], and provide extended red response[4,5], smaller point-spread function[6,7] and improved radiation tolerance[8,9] relative to conventional astronomical-grade CCDs. The CCD package design is driven by requirements for the focal plane CCD array of the proposed SuperNova/Acceleration Probe (SNAP) satellite[10,11]. The present version of the SNAP focal plane incorporates four arrays of 3×3 CCDs, for a total of 36 devices[12]. Each CCD has 3.5k×3.5k, 10.5 μm pixels, for a total of almost one-half billion pixels in the visible portion of the focal plane. A similar arrangement of four 3×3 near-infrared (NIR) sensor arrays is also planned[13]. The preliminary SNAP design requirements for the CCD package are:

- Focal plane flatness and co-planarity excursions ≤ ±10 μm
- Shim free, precision cold plate integration
- Good thermal contact
- Good temperature uniformity across the CCD
- Good vacuum behavior with no out-gassing
- Zero radioactivity materials
- Easy exchange of devices
- Minimal weight and expense
- Consistent with SNAP NIR detector constraints

In this paper we describe a packaging approach that has successfully met the preliminary SNAP design criteria. In addition to research and development for SNAP, this packaging effort was undertaken with the goal delivering CCDs to the professional astronomical community, allowing LBNL CCDs to be more widely deployed and to obtain data from professional users. The package we describe here is of the format employed for the first device delivered.

In Section 2 we describe the package design including material choices and mechanical, thermal, and electrical considerations. Section 3 describes the packaging implementation including hardware, procedures, and quality assurance. Section 4 describes the package performance including measurements of flatness and optical tests. Section 5 we discuss the advantages and disadvantages of our current package design and describe our plans for further research and development on a 4-side buttable packaging solution, building on the experience gained in this work.

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2. Package Design

The purpose of the CCD package is to provide electrical, mechanical and thermal connectivity between the CCD and the necessary external systems while maintaining a high degree of mechanical precision, stability and robustness, as well as thermal uniformity and reliable electrical connections. Additionally, the package design is constrained by the geometry and layout of the CCD. Below we describe how package materials were selected and provide an overview of the thermal, mechanical, and electrical design.

2.1 CCD Geometry

The CCD geometry guides the package design in three ways. First, the package should match the CCD dimension well, exceeding it in size by no more than 1 mm on three sides and by no more than 2 mm on the fourth side. Second, the location of the bond pads on the front-side of the CCD determines the electrical layout of the package. Third, the package should not induce stress in the CCD upon being cooled to cryogenic temperatures, as this may distort the image quality. This requirement drives the selection of package materials that may apply stress to the CCD by contracting or warping. We will describe below in Section 2.6 how the package is designed to match the CCD coefficient of thermal expansion (CTE). Figure 1 shows the layout of our 2k×4k CCD indicating bond pad positions and dimensions.

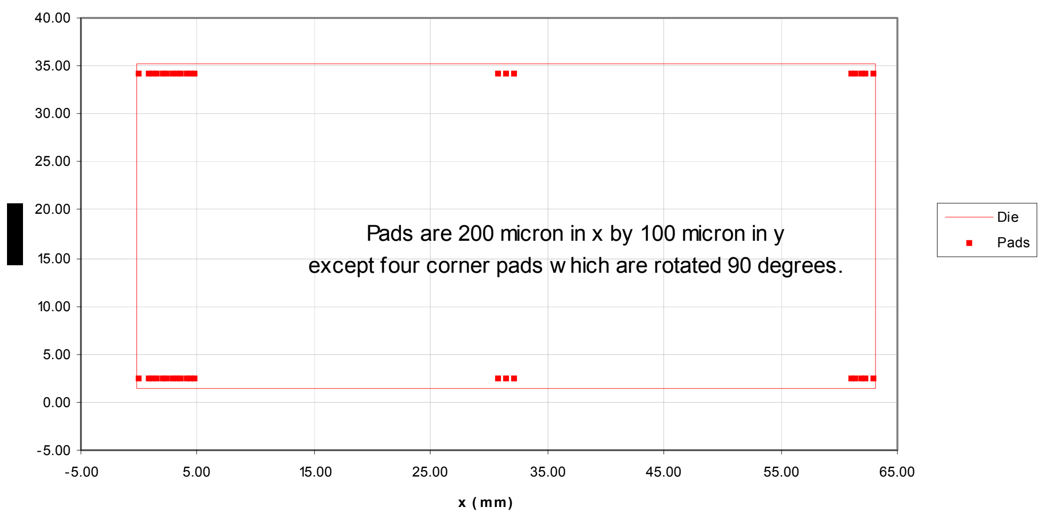

Figure 1. Layout for LBNL CCD 2k × 4k format devices

2.2 Materials

The package consists of three parts: a printed substrate that is glued directly to the CCD, providing mechanical support and electrical connectivity, a metal mount (or "foot") that provides the mechanical interface with the cold plate, and an electrical connector that provides a mate-able contact between the substrate circuit and the CCD camera. Equally important material choices are the epoxy that bonds the substrate to the CCD and the substrate to the foot, and the solder that bonds the electrical connector to the substrate. Figure 2 shows drawings of the CCD package design. This section describes the material choices for the substrate, foot, and epoxies.

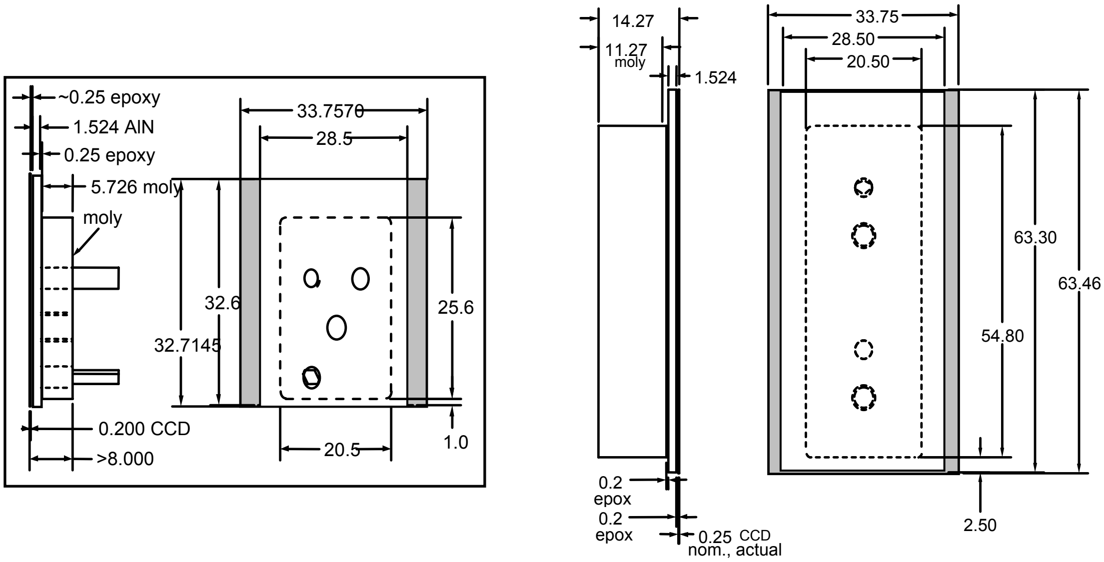

Figure 2. Four side buttable package designs for 2k×2k and 2k×4k devices (units in mm).

Substrate. The substrate serves as the heart of the package, as all other package parts are attached to it. Since the CCD is operated at cryogenic temperatures (~140 K) it is important that the substrate have a CTE that closely matches that of silicon (Si), the CCD material. The substrate must also be capable of carrying printed electrical circuitry. Also, our choice of connector requires that we be able to solder to the substrate. Finally, as mentioned above, all our package parts must be non-radioactive. For all these reasons aluminum nitride (AlN) was selected as the substrate material. Figure 3 shows plots of the coefficient of thermal expansion for Si, AlN, Invar42 and molybdenum (Mo).

Ideally, one would want to match the CTE of the CCD exactly. The only material that would do this is Si. We have explored the option of using a silicon substrate but have focused our initial efforts on utilizing AlN as Si can not be soldered as required by our connector choice. Also, as we will describe below, the Si substrate thickness required would be about three times the standard Si wafer thickness, hence, introducing additional difficulties. Nonetheless, in Section 4.2 we will present data on the behavior of a Si substrate in our application.

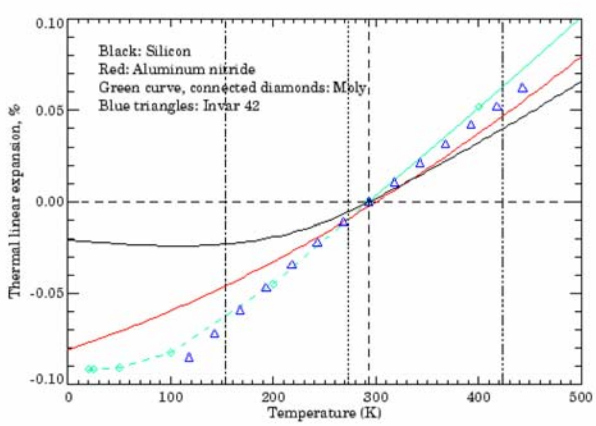

Figure 3. Thermal expansion coefficients for Si, AlN, Mo, and Invar42

Foot. The foot material must be non-radioactive and have a CTE that closely matches that of Si. The foot material has the additional requirement that it be machine-able and rigid as it provides the precision interface with the cold plate. Mo was chosen over Invar42 because Mo is stiffer, has higher thermal conductivity (~14×), and is difficult to oxidize, while having a CTE match to Si nearly as good (see Figure 3). We do note that the CTE of Invar36 matches Si better than Mo and Invar42, which are nearly identical.

The choice of the foot material was also influenced by SNAP focal plane design considerations; in the current SNAP design the cold plate is Mo. Also mounted on the cold plate will be commercially packaged HgCdTe sensors that utilize a Mo package. Hence, Mo was chosen also in order to be most congruent with the current SNAP design.

Epoxy. Our approach to bonding the CCD and foot to the substrate differs from that of others. The standard adhesive used in the astronomical CCD community is EPO-TEK 301-2, designed for bonding optical fibers at room temperature. While many users have successfully utilized this particular epoxy, we deviated from this approach for two main reasons. First, the EPO-TEK epoxy is not designed to operate at cryogenic temperatures; discussions with the manufacturer lead us to believe that it may not perform reliably under repetitive thermal cycling. EPO-TEK is not compliant (i.e. has a high glass transition temperature), has low strength, and a CTE substantially different from the package parts. In our application the EPO-TEK would be overstressed, creating the chance of breakage with enough cold cycles. Second, the LBNL CCD is ~10 times thicker standard astronomical CCDs and thus behaves more like a beam than a membrane. The low viscosity, stiff EPO-TEK epoxy would form a very thin layer between parts and would transfer any mechanical stresses due to differential contraction upon cooling from one part to another. We desire an epoxy bond that is thick enough and compliant enough to take up any stresses induced in the package by differential expansion rather than transferring them to the CCD. The largest expansion differentials occur between the Mo foot and the AlN substrate. The desires to relieve stress in this joint and reliable cryogenic performance are the primary drivers for the epoxy type and thickness.

We chose the epoxy Hysol EA9361; it has a low glass transition temperature and is intended for use at 80K. It is also compliant, possessing a low Young's modulus. These factors contribute to low stress in the glue and low transfer of stress from one part to the other. We also use a fairly thick glue layer (~250 μm) to minimize the amount of stress transfer. To determine if the Hysol epoxy is fully compatible with our required epoxy characteristics it was tested for mass loss, outgassing, shear strength, shear modulus, bending modulus, CTE, thermal capacity, thermal conductivity, and radioactivity. We describe those tests in Sections 2.5, 2.6 and 4.1.

2.3 Cold Plate Interface

The foot mates the CCD package with the cold plate. We require shim-free precision device co-planarity and alignment settings to be designed into the package. The device height is set in the package assembly and co-planarity is assured by adjusting the thickness of the epoxy layer that bonds the foot to the substrate for each device such that all packaged devices are the same height (see Section 3). On the other hand, precise positioning of pixels is not required as pixel position will be mapped. Nonetheless, mounted detectors are located by registration pins on the cold plate so that they can not shift once in place. Devices are held in place by one or two screws, depending on the device format, that attach through the cold plate and into the foot. For device placement on the cold plate, long thin handling rods are screwed into the holes in the foot and used to lower devices in place. The length and positioning of the registration pins yields it impossible for devices to collide while being placed in the cold plate in the presence of other mosaic CCDs.

2.4 Electrical Interface

The substrate connects the on-chip CCD electronics with the CCD control electronics. Electrical connectivity from the CCD to the substrate can be made with either wire bonds or bump bonds. Electrical connectivity from the substrate to the control electronics is made via an electrical connector permanently attached to the substrate and a wiring harness. For the current package design, wire bonds were chosen to connect the CCD to the substrate due to the ease of implementation. Had we chosen bump bonds, a less viscous epoxy would also be required in order to back-fill the CCD/substrate joint after bump-bonding. The epoxy chosen is highly viscous and not likely to perform well in this implementation. Also, bump bonds generally require a thin glue joint, which would rule out the thick glue joint chosen to take up stress that might otherwise be transferred to the CCD.

Electrical connection between the substrate and the electronics is done using a Nanonics 37-pin connector. This connector is rated for over 2000 connections/reconnections, is free of crosstalk in our application, and utilizes a reliable mechanical mating system.

2.5 Thermal Model

We require good thermal contact between the CCD package and the cold plate and also between all CCD package parts. The Si CCD, AlN substrate and Mo foot materials are all known to have excellent thermal conductivity. Therefore, our primary concern is to determine the thermal conductivity and uniformity of the epoxy layer. Figure 4 shows a model simulating the thermal gradients in the glue layer as utilized in our application. The data shows that the glue layer will have a temperature range of only 0.15 K at our operating temperature of 140K, well within specification.

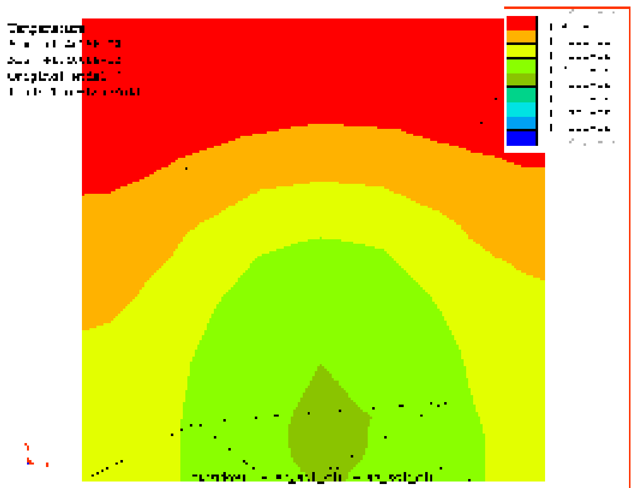

Figure 4. Thermal model of the epoxy layer

2.6 Package Materials' Dimensions

The AlN and Mo *xy*-dimensions were chosen to support the CCD as completely as possible, while leaving adequate clearance for access to the CCD bond pads and connector. The total package thickness was set by the requirement that it be stiff enough that the CCD not bow more than the allowable amount, ±10µm. The total amount of bowing is a function of the stiffness and thickness of the AlN, Mo and CCD, their linear dimensions, their CTEs, and the glue bondline thickness and shear modulus. The minimum allowable bondline thickness for the epoxy such that its stress and strain remained at least a factor of four to five beneath failure was calculated. The AlN thickness was chosen to have an equivalent stiffness to the CCD. The Mo outshrinks the AlN/Si, compressing its center. The silicon and the glue are too thick and not stiff enough to resist bowing, so that resistance must come from the Mo. This determined its thickness.

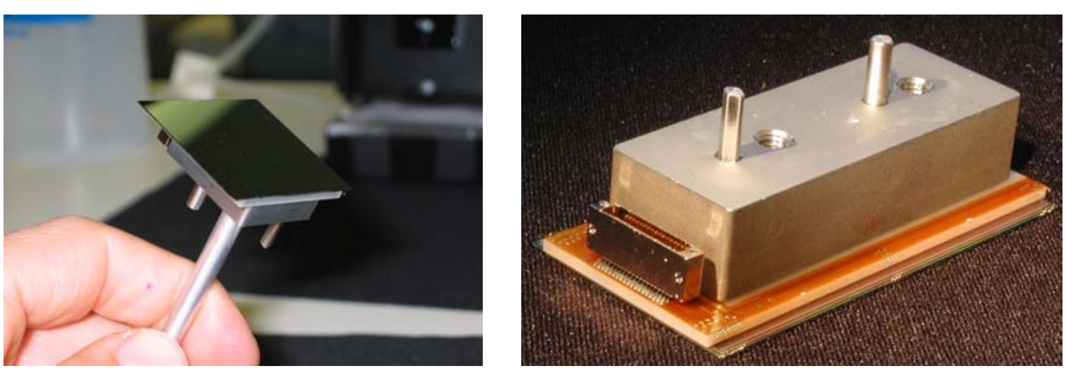

Figure 5. Packaged four side buttable LBNL 2k×2k and 2k×4k CCDs

3. Packaging Implementation

3.1 Packaging Fixtures

Custom fixtures were designed for assembling 2k×2k and 2k×4k CCDs based on our 4-side buttable package design. The fixtures provide repeatable and reliable results in the package alignment, flatness and thickness. There are two main parts: the glue fixture, which uses interchangeable vacuum chucks customized for each CCD format, and the glue masks which aid in the dispensing of epoxy. We describe each part in detail below.

Glue Fixture. The glue fixture was designed to provide precisely aligned bonds between the CCD, the AlN substrate and the Mo foot. The fixture consists of an upper carrier plate to which the upper vacuum chuck is mounted; the guide shaft; and a baseplate that holds the lower vacuum chuck, three spacers, two front alignment shafts, and the lowering knob**.** Both the upper and lower vacuum chucks have three alignment pins for accurate CCD and AlN substrate registration. The Mo foot alignment is obtained using the foot alignment pins and screw attachment holes; it is mounted directly to the baseplate after the lower vacuum chuck is removed. Figure 6 shows the gluing fixture with a 2k×2k CCD on the upper vacuum chuck and an AlN substrate with a glue patch on the lower chuck.

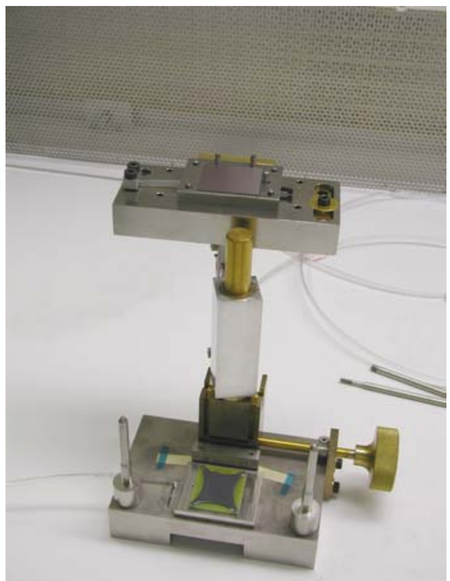

Figure 6. The gluing jig with a CCD in the upper carrier plate and an AlN substrate with glue patch on the lower plate.

Glue Masks. The highly viscous Hysol epoxy is applied utilizing glue masks designed such that a glue patch on one mating surface expands to the edges of the joint when the bonding surfaces are brought together. Their thickness was carefully determined to allow the glue to completely fill the mating space without extruding out of the joint and creating a fillet. The glue mask geometry is such that when it is placed on the lower part to be glued and filled with glue, the glue patch is twice its final thickness and shaped so that when the glue is compressed to the correct thickness by lowering the upper part onto it, the glue assumes the correct rectangular shape with small radii at the corners of the rectangle.

3.2 Packaging Procedures

Our packaging proceeds in 6 steps: 1. Solder electrical connector to AlN substrate, 2. Inspect AlN substrate for shorts and opens, 3. Epoxy CCD to AlN substrate, 4. Wire bond CCD to AlN substrate, 5. Epoxy Moly foot to AlN substrate, 6. Inspect CCD for shorts and opens.

Step 1: Electrical Connector Attachment. Solder paste is applied to the AlN connector pads, the connector is carefully aligned to the pads, and the part is run through a prescribed bake cycle.

Step 2: AlN Inspection. After attachment the AlN connector pads are visually inspected for obvious shorts resulting from the soldering process. A testing harness is then mated to the connector, the assembly is placed in a probe station and the AlN substrate is tested for shorts and opens prior to CCD attachment.

Step 3: CCD to AlN Substrate Attachment. The AlN substrate is aligned and secured on the glue fixture's lower vacuum chuck with the connector facing downwards. A glue mask is placed on upper surface of the substrate and pre-mixed and degassed epoxy is applied using a syringe. A large glue patch is applied over about a third of the glue mask and is then "squeegee-ed" smooth with a razor blade (Figure 7).

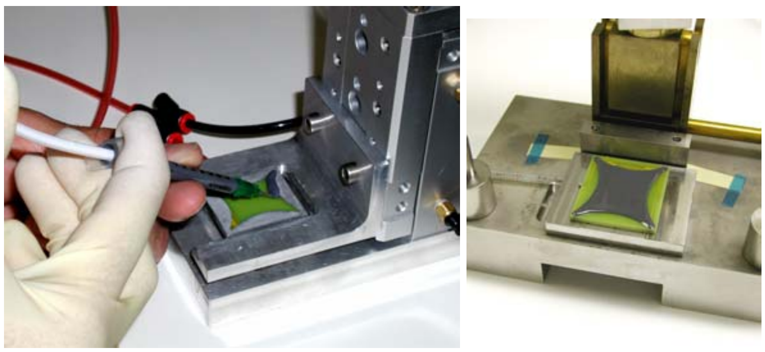

Figure 7. Application of a glue patch using a glue mask

This empirically developed technique results in repeatable glue thickness and distribution. Note that the CCDs vary in their thickness by ±10 µm. we are able to make all packaged part the same thickness by adjusting the thickness of the glue layer between the CCD and AlN substrate. CCDs are delivered with a scrap portion of the wafer that they were fabricated upon. The thickness of the wafer is measured and shims are placed on the glue jig to insure that the CCD/epoxy/AlN substrate sandwich is always within a micron of the desired thickness, depending on the device format. This requires glue masks of varying thicknesses.

Precision alignment is critical when attaching the CCD to the substrate. The CCD on the upper chuck is butted against three alignment pins for in-plane alignment. The upper chuck is aligned with the lower chuck using three alignment shafts affixed to the fixture base plate and through holes in the upper plate. Flatness is obtained by bringing the upper chuck down onto spacer shims located on the spacer blocks in the base plate. Once the upper chuck is snug on the spacer shims, the shims are removed and the upper chuck is lowered onto the base plate spacers. As the CCD is lowered to its correct height above the AlN substrate, the glue patch spreads uniformly to cover the surface of the substrate without extruding beyond its edges. A weight is then placed on the fixture to maintain uniform pressure between the upper carrier and the spacers. The weight is supported by the upper carrier plate, which is supported by the lower carrier plate's precision spacers. Neither the CCD not the AlN substrate support the weight. The epoxy takes 24 hours to cure at room temperature.

Step 4: Wire Bonding. The device assembly proceeds by wire bonding the CCD to the substrate. The vacuum line, which holds the substrate to its vacuum chuck, is removed. The weight is removed and the upper carrier, with the CCD/AlN attached to its vacuum chuck, is lifted from the lower chuck. The vacuum chuck is then removed entirely from the glue fixture, inverted and taken to a nearby wirebonder where forty Al wedge bonds are made. Once bonded the CCD/AlN package is taken back to the glue fixture for the Mo foot attachment.

Step 5: Mo Foot Attachment. To attach the Mo foot, the lower vacuum chuck is removed from the glue fixture and the Mo foot is attached to the fixture in its place, utilizing the same alignment and screw holes that held the lower vacuum chuck. A patch of epoxy is placed on the Moly foot using a glue mask in exactly the same manner in which the first glue patch was made. The upper chuck with the CCD/AlN package is then brought down into contact with the precision spacer blocks, the Mo foot maintaining precision alignment as before. The weight is placed on the assembly and the epoxy is allowed to cure.

Step 6: CCD Inspection. The CCD is tested for shorts and opens using test harnesses and a probe station. A harness is attached to the CCD electrical connector which allows easier access to the connector lines. Each connector line is tested against its corresponding CCD pad to insure electrical connectivity. Likewise, each connector line is tested against all other lines to determine if any shorts are present.

3.3 Quality Assurance

Care is taken to avoid electrostatic damage (ESD) to the CCD, damage to the CCD optical surface, and to maintain device cleanliness. Assembly steps take place inside a class 10,000 clean room. The assembly work bench has an air ionizing strip mounted under a laminar flow hood. The work bench surface is charge dissipative as are the work bench stools, and the floor. Additionally, the assembler is electrically grounded using charge dissipative wrist straps and also wears charge dissipative gloves, and shoe covers. The assembly and wire bonding work areas are in close proximity and the assembly fixture is outfitted with a removable, traveling chuck. When the CCD is taken from the gluing fixture to the wire bonder (and back), the device never leaves its vacuum chuck, avoiding any dust or scratches.

4. Package Performance

Prior to implementing the package described above with an actual CCD, extensive measurements of the epoxy and package performances were carried out on test prototypes. Below we describe these tests in detail. Optical tests of a fully assembled device are also described.

4.1 Epoxy Tests

An important criterion for the epoxy used to bond the CCD, substrate and foot is that it not outgas significantly. Outgassing tests were performed consistent with NASA specifications[14]. We obtained from NASA Goddard Space Flight Center their test data for the epoxy Hysol XEA9361, the predecessor of Hysol EA9361 used in our package.

The Goddard test method used was ASTM E595-77/84/90; details are at http://outgassing.nasa.gov/og_desc.html.

We briefly note the three step method here:

- Pre-condition epoxy for 24 hours at 25C, 50% relative humidity (RH), 1 atmosphere pressure
- Place epoxy in vacuum for 24 hours at 125C
  - Measure total mass loss
  - Collect and measure volatile condensable materials
- Place epoxy at 1 atmosphere pressure for 24 hours at 25C, 50% RH
  - Measure water vapor regained

The Goddard tests showed a total mass loss rate of 1.54% and volatile condensable materials of 0.06% with 0.21% water vapor regained for XEA9361. We repeated the Goddard tests using our epoxy, Hysol EA9361, but with conditions slightly modified to simulate our own bonding and storage conditions. Our test was run at 15C rather than 125C to approximate our fabrication and storage conditions. We also simulated 2k×4k CCD bonds. The absolute outgassing mass loss rate was 2E-7 torr/sec/bond. We did not measure the water vapor regained as our application will be in space. We did, however, determine the identities of the molecular species generated. Table 1 gives the outgassing species and pressures by mass. Note that other species were generated but unidentified – likely cracked long-chain molecules, down by a factor of 100. The total mass loss after 31 days in vacuum was 0.24%, all atmospheric gasses.

Table 1. Measured mass loss rates from 5 2k × 4k glue bonds

Species	Partial Pressure (E-10)	Fraction of Total (%)	Rate (std cc/sec)	Density (g/cc)	Mass rate (10^{-3} g/1000 dys)
H_2O	50	71	19	0.00183	12
H_2	10	14	3.9	0.00117	0.27
N_2	7	10	2.6	0.0000836	2.7
CO_2	3	4	1.1	0.00183	2.3

4.2 Flatness Tests

Device flatness and co-planarity are two of our most stringent device specifications. Several aspects of our package may degrade its flatness. First, the epoxy layer may cure from the exposed edges in towards the middle, which may introduce stresses in the CCD. Second, the package may warp due to differential CTEs when it is cooled from room temperature to 140 K, the nominal CCD operating temperature. Finally, it is possible that we may have systematically introduced a tip or tilt in the package due to misalignment in the assembly fixture.

Figure 8, shows the measured flatness of a packaged 2k×4k device. The edges of the CCD are curled up relative to the center. Nonetheless, the measured deflection is within our ±10 μm specification.

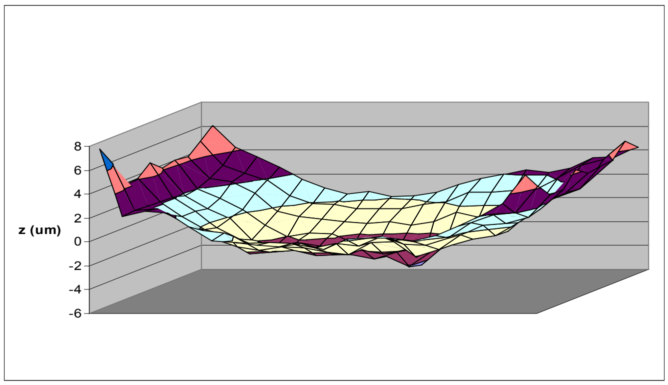

Figure 8. Measured flatness of a fully packaged 2kx4k device

A speckle interferometer was used to determine the device deflection upon cooling from room temperature to the device operating temperature, 140 K. Figure 9 shows the measured deflection from cooling for a fully packaged 2k×4k format device. The maximum range of the measured deflection for this device was 6.5 μm.

The full deflection comes from the sum of the original deflection as shown in Figure 7 and the deflection upon cooling shown in Figure 8. The direction of the deflection due to cooling is opposite the direction of the original deflection. These results indicate an integrated flatness deviation near 1 μm at the operating temperature of 140 K.

We also have explored the idea of utilizing a Si substrate in our package design. Therefore, deflection tests were also carried out on fully packaged devices utilizing a Si substrate instead of an AlN substrate Table 2 gives the measured deflections for both package types and formats using blank AlN, patterned AlN, and blank Si substrates. Note that the measured peak to peak deflections are all well within our ≤ ±10 μm specification.

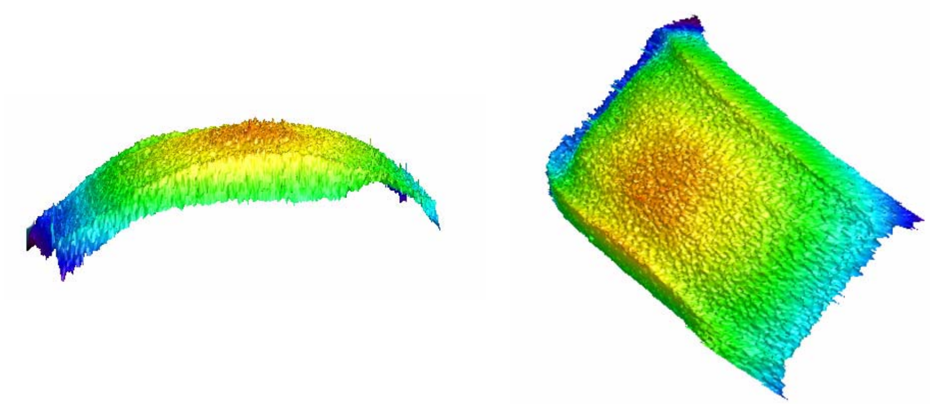

Figure 9. Measured deflection of a 2kx4k device when cooled to 140 K. The maximum deflection is 6.5 μm.

Table 2.
Measured deflection of packaged 2k × 2k and 2k × 4k devices of various configuration when cooled to 140 K

Package	Deflection Δz (μm)
2k × 2k AlN blank	6.5
2k × 2k Si blank	3.8
2k × 2k AlN Patterned	7.0
2k × 4k AlN blank	6.5
2k × 4k Si blank	3.5
2k × 4k AlN Patterned	6.9

4.3 Optical Tests

The developed 4-side buttable CCD package was initially implemented with an engineering grade device to verify operability. Once verified, potential science grade CCDs were packaged. Bias and flat field images were obtained to determine if any package-induced cosmetic defects were introduced. Figure 10 shows a bias frame, resolution bar target image, and a 10,000 electron level green flat field image (650 ± 21 nm). Obvious cosmetic defects include residuals from the glue line and from the vias in the AlN substrate that have "printed" through to the CCD.

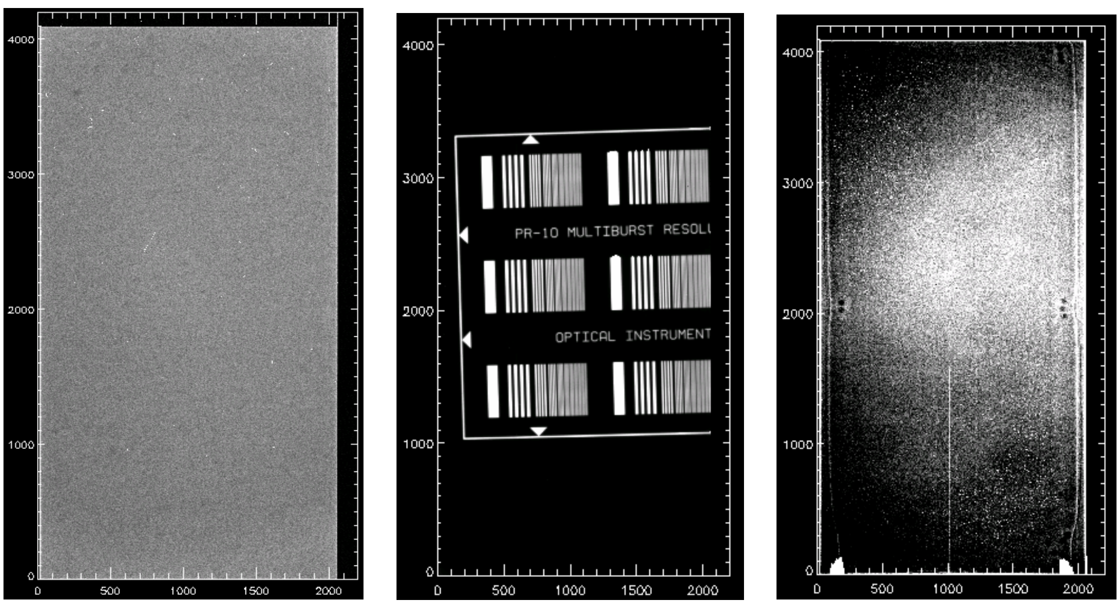

Figure 10. A bias frame, a resolution bar target image, and a green flat taken with a packaged 2kx4k device.

An examination of the packaged device revealed that epoxy flowed into and filled the vias near the CCDs edges. These vias show a ≤ 6% reduction in response from the image median level (Figure 11). Note that there is also a faint bright halo surrounding the depressed circles that correspond to the locations of the vias. On the other hand, vias under the electrical connector show an enhanced response compared to the median value. Because of the presence of the connector it is not possible to determine if epoxy flowed into and filled them, though we believe it is unlikely. The electrical connector would have vias are "capped" those vias and created an air pocket which would likely prevent epoxy from flowing into them. Note finally that the outside the glue line the edge of the AlN is also apparent.

The glue line shows depressed emission of ~ 6% on the interior side and enhanced emission of < 1% on the exterior side. These cosmetic defects raise several questions: Can the via and glue line residuals be removed with standard astronomical flat-fielding? Are there temperature or wavelength dependent effects in the flat-field subtraction? Do via and glue line residuals represent 6% changes in the device's quantum efficiency or are they due to an optical or electrical distortion? Why is the edge of the AlN visible? We briefly discuss these questions below.

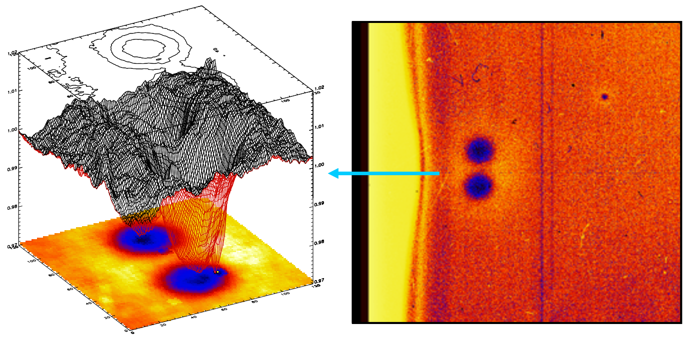

Figure 11. Glue line and two vias illustrating depressed emission in their centers and enhanced emission around their edges

A measurement was made of the degree to which the residuals flatfield out. Flat illuminated frames at ≥40,000 e^- were obtained in each of two colors (B = 450 nm, R = 1 μm), at two temperatures, ΔT~10 K. Average deviations below the median value caused by the vias were: B=-3.84%, R=-8.09%. Ratios taken between images of the same color flatfielded to <0.5%: B/B=0.02%, R/R=0.30%. At the same color but between temperatures the vias deviated by: $B/B_{\Delta T}$=0.13%, $R/R_{\Delta T}$=1.52%. Between colors and temperatures the deviation was: B/R=2.85%, $B/R_{\Delta T}$.=3.49%. The glue line and AlN edge residuals flatfielded to better 0.5% in all cases. Recall that the vias capped by the metal connector appeared brighter rather than darker. Also, the effect is greater in the red than in the blue. Together, these suggest that the residuals are caused, at least in part, by light scattering backwards through the device from the AlN/air and AlN/metal interfaces. The presence of the vias would suppress this effect, qualitatively consistent with the data. Note, however, this explanation predicts a Mo foot residual, an effect which is not seen.

To determine if the residuals are due to stress we placed an illuminated bar tangent to and through the vias to see if we saw evidence of charge redistribution. We noted any change in the position of the bar and any effect on the integrated brightness of the bar. The shift of the bar was measured by fitting a Gaussian and noting any systematic shift of the center of the Gaussian versus row number. At the positions of the vias the line was shifted by about 0.35 pixels. There was no discernable effect on the integrated brightness of the bar. To decouple this effect from a purely optical effect, i.e. QE depression; we simulated purely optical vias. It was determined that a QE depression of ~19% was necessary to reproduce the 0.35 pixel shift seen. We conclude, therefore, that stress also plays a factor in creating the via and glue line artifacts observed. Perhaps a distortion in the electric field inside the device redistributes charge in the stressed regions. In any case, the via and glue line artifacts are localized to the device edges. Hence, the device may still be used in either an imaging or spectroscopic camera. In future development we will eliminate these artifacts.

5. Discussion

We have developed a package satisfying our initial goals. The device flatness has been measured to be within about ±3 μm at operating temperature of 140 K. The total device thickness can be controlled to within ± 1–2 μm from device to device. Thermal uniformity is within ~0.20 K. There is no substantial outgassing and the small amount of gasses liberated are all atmospheric, primarily water. This is not a problem in the terrestrial application. For space the devices may be placed in vacuum prior to integration. The mechanical design yields easy exchange of devices in the focal plane. The devices are fully 4-side buttable with minimal wasted area. Our electrical connector was tested for robustness through ~25 insertion/reinsertions and performed reliably.

We have identified several ways in which the current approach may be improved. Most notably, the presence of the via and glue line residuals should be removed. Future developments shall require that there be no inhomogeneous structure under the CCD active area. Also, opaque AlN may be used in place of standard AlN to prevent any back reflections from the AlN/air or AlN/metal interfaces. Fortunately, the artifacts can be flatfielded to less than one percent – even across temperatures. Still, the artifacts should be avoided as there is some preliminary evidence of charge redistribution. Finally, we may replace the Mo foot with an Invar36 foot, which has a better CTE match to Si and AlN.

We are currently exploring a bump-bonded Si substrate package with an Invar 36 foot to improve flatness and remove structure beneath the CCD active area. This, unfortunately, necessitates sacrificing 4-side buttability as we can not solder a connector onto the backside of a Si substrate as was done with the AlN substrate. Instead the Si substrate will extend beyond one end of the CCD and can be wirebonded to circuitry carrying the connector – the standard format in current large mosaics consisting of 3-side buttable packaged devices.

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REFERENCES

1. S. E. Holland, *et al.*, “A 200 x 200 CCD Image Sensor Fabricated on High-Resistivity Silicon," *IEDM Technical Digest*, **911**, 1996.
2. C.J. Bebek, *et al.*, “Fully depleted, back-illuminated p-channel CCD development,” in *Focal Plane Arrays for Space Telescope, Proceedings of SPIE* **5167**, 2003.
3. S.E. Holland, *et al.*, “Fully Depleted, Back-Illuminated Charge-Coupled Devices Fabricated on High-Resistivity Silicon,” *IEEE Transactions on Electronic Devices* **50 (3)**, 2003.
4. R.J. Stover, *et al.*, “Characterization of a Fully Depleted CCD on High Resistivity Silicon," in , *Proceedings SPIE* **3019**, 1997.
5. D. E. Groom, *et al.*, “Quantum Efficiency of a Back-illuminated CCD Imager: An Optical Approach,” in , *Proceedings SPIE* **3649**, 1999.
6. A. Karcher *et al.*, “Measurement of Lateral Charge Diffusion in Thick, Fully Depleted, Back-Illuminated CCDs,” *IEEE Transactions on Electronic Devices* **50 (3)**, 2003.
7. D. E. Groom, *et al.,* “Point-Spread Function in Depleted and Partially Depleted CCDs,” in *Proceedings 4th ESO Workshop on Optical Detectors for Astronomy*, 1999.
8. C. J. Bebek, *et al.,* “Proton Radiation Damage in High-Resistivity N-Type Silicon CCDs,” in , *Proceedings of SPIE* **4669**, 2002.
9. C. J. Bebek, *et al.*, “Proton Radiation Damage in p-Channel CCDs Fabricated On High-Resistivity Silicon,” LBNL-49316*, IEEE Trans. Nucl. Science* **49**, 2002.
10. G. Aldering *et al.*, “Overview of the SuperNova / Acceleration Probe,” in *Survey and Other Telescope Technologies and Discoveries*, *Proceedings of SPIE* **4836**, 2002.
11. M. Lampton *et al.*, “SNAP Telescope,” in *Survey and Other Telescope Technologies and Discoveries*, *Proceedings of SPIE* **4849**, 2002.
12. M. Lampton *et al.*, “SNAP Focal Plane,” in *Survey and Other Telescope Technologies and Discoveries*, *Proceedings of SPIE* **4854**, 2002.
13. G. Tarlé *et al.*, “The SNAP Near Infrared Detectors,” in *Survey and Other Telescope Technologies and Discoveries*, *Proceedings of SPIE* **4850**, 2002.
14. http://outgassing.nasa.gov/cgi/sectionc/sectionc_html.sh